GTRI

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 9/18/80

Project Title: Planning and Estimating in the MAF

Project No: E-20-645

Project Director: Dr. Daniel W. Halpin

Sponsor: Naval Construction Battalion Center

Agreement Period: From April 25, 1980 Until ~~August 29,~~ Nov 30 1980

Type Agreement: Order No. 62583/ 80 M R537

Amount: $9,200

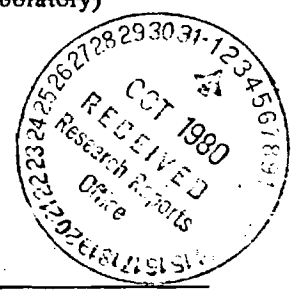
Reports Required: Monthly Progress; Final

Sponsor Contact Person (s):

Technical Matters	Contractual Matters (thru OCA)
L.C. Tucker Supply Officer Naval Construction Battalion Center Port Hueneme, CA 93043 (805) 982-5904/4815	

Defense Priority Rating:

Assigned to: Civil Engineering (School/~~Laboratory~~)



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CA–3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
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SPONSORED PROJECT TERMINATION

Date: 4-24-81

Project Title: Computer-Aided Design for MAF Engineers

Project No: E-20-645

Project Director: Dr. D. W. Halpin

Sponsor: Naval Construction Battalion Center

Effective Termination Date: 11/30/80

Clearance of Accounting Charges: 11/30/80

Grant/Contract Closeout Actions Remaining:

- x Final Invoice~~and Closing Document~~
- _ Final Fiscal Report
- x Final Report of Inventions
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CA–4 (1/79)

E 20-645

SCEGIT–80–194

PLANNING AND ESTIMATING FOR THE MAF ENGINEER

AN INVESTIGATION CONDUCTED BY
THE SCHOOL OF CIVIL ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

By

D. W. HALPIN, Project Director

Prepared for

THE U.S. MARINE CORPS
CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
PORT HUENEME, CALIFORNIA

Under

PURCHASE ORDER N62583/80 MR537
WITH THE OFFICER IN CHARGE OF CONTRACTS

December 1, 1980

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL ENGINEERING
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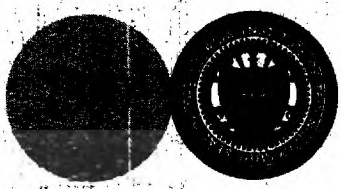

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DECEMBER 1, 1980

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INTRODUCTION

Support for the Marine Amphibious Force (MAF) in an Amphibious Objective Area (AOA) requires the development of an adequate, efficient manpower utilization plan. During the amphibious operations and subsequent tactical operations, the availability of construction forces to build the base camp and perform combat engineer tasks will normally be limited. It is necessary, therefore, to insure the maximum utilization of available engineer effort to carry out the construction requirements that correspond to scheduled operational readiness dates according to the commander's priorities.

The level of construction effort required for the operation depends upon the characteristics of the individual projects that make up the operation. The daily or period-by-period construction effort of individual projects is characteristic of the type of work being performed. The general characteristics of the daily or period-by-period manpower effort required can generally be determined by experience from similar projects or the use of existing design procedures which generate effort required. In fact, many types of activities can be seen to follow a small number of specific curves which graph manpower effort expended over time. If all projects comprising the MAF operation are thus analyzed and graphed, comparison of available versus required assets can be performed and adjustments made. This can provide the basis for an optimal overall utilization of resources providing that some individual activities can be moved to an earlier or later start or completion dates. Factors other than construction considerations, such as tactical plans and operational requirements must

be taken into account.

The actual shifting of individual activities in an overall schedule for an operation is an iterative process that begins in the planning and estimating stage of the operation and may be carried out well into the actual operation itself. The planning process results in a task assignment and schedule that is reflected in the Engineer Annex to the Operations Order. Additionally, modifications and changes can be expected throughout the operation. The purpose of this study is to develop and demonstrate a manpower planning technique which will enable planners in the MAF to use a methodology which will lead them towards an optimum manpower schedule.

BACKGROUND

The preparation of a proposed plan of activities during development of the AOA has been traditionally in part based upon the intuition of the Command Staff. A team of engineer planners familiar with the tactical plan, construction practices, and base development requirement develops a schedule for the operation. This schedule consists of individual projects sequenced in time so as not to exceed available effort and still accomplish the construction requirements of the operation within the commander's initial guidance. Of prime consideration is the allocation of engineer manpower, equipment and material resources over time in a manner which allows the detection of conflicts between the resources available and needed. Having detected such conflicts, the planner must reconcile them by making adjustments. During the planning stages, the MAF engineer has relatively limited information regarding the levels of required as well as available resources. Given this limited information, which is subject to fluctuation as more detailed information becomes available, the planner must have a flexible, easy to use tool which allows the display of both resource availability and requirements throughout the duration of the operation. This study has focused upon the estimation and planning of manpower requirements versus availability over the duration of the operation. The objective of this study has been to develop a conceptual framework and prototype computer program for a small computer (microcomputer) based system which allows the MAF engineer to display manpower estimates versus requirements over the duration of the operation. The system is designed to use estimates ranging from very tentative to more precise regarding the manpower situation.

The simplicity of the concept readily permits update of the system information data base as the operation evolves. The system simplicity also provides the planner a framework within which to detect resource conflicts and thus the ability to reschedule and resolve such conflicts.

The "operation" in this report is defined as the collection of construction projects that comprise the operation. Each project is also made up of subparts which are termed "project sub-activities."

EXISTING SYSTEMS

The very nature of military construction in a tactical environment creates special considerations. Even civilian construction has developed and refined construction management techniques for large scale projects, so have the military engineer staffs developed management systems at the permanent facilities level. The Army's facilities Component System (AFCS) provides a complete system intended primarily for base development in the theater of operations. Not only drawings, but extensive logistical data and engineer troop effort are available for a large variety of installations in arctic, desert, tropical or temperate climates. A computer-aided base planning system, called the CASTLE project, was the Army's initial attempt to put forth a base planning management system using AFCS extimates as the data base. A later development, called the Civil Engineer Support Plan Generator, is a highlevel planning instrument taking into account all engineer assets (multi-service) in the theater of operations. This system uses the latest revised AFCS System as a data base for computations. To process base development estimates and calculations, a large host computer such as a UNIVAC Series 1100 level machine is needed. Even with such a system, computing times of 45 minutes for division-level operations are not uncommon. Also available to both military and civilian planners are various automated CPM and PERT network systems. These tools, while aiding in the management of individual projects, do not provide the necessary flexibility to project an overall view of the manpower demand on a day-by-day basis given the limited detail available during the planning phases of an operation. These methods also tend to be too rigid in the dynamic situation which obtains at the MAF engineer level during the development of the AOA.

Systems like the CASTLE project and the Civil Engineer Support Plan Generator provide a valuable planning tool at the Joint Chiefs of Staff (JCS) level, but little is available at the operational planning level of the MAF engineer. One system at this level was suggested in a report written at the U. S. Army Construction Engineering Research Laboratory, entitled "A Data-Based Methodology for Specifying Construction Project Duration." This Technical Report proposes using previous construction experience to develop curves for relatively broad areas of construction such as site work, roofing, and similar building construction activities. These curves in turn would be used to determine durations for those broad areas of the proposed project thus determining an overall duration for the project.

METHODOLOGY

Estimating construction effort for a construction task is not new, either to civilian contractors or to military engineers. A variety of factors and considerations must be taken into consideration. In a MAF type operation these factors can be lumped into two groups: (1) construction, and (2) operation. The construction objective function can be evaluated based on the utilization of available manpower to construct a facility. On the other hand operational factors would involve the effort required to maintain a facility at a certain level of performance.

To evaluate the relative merits of various alternatives a common denominator is required. In the civilian arena the common denominator upon which alternatives are evaluated is dollars. This is not an appropriate basis for evaluation in the MAF type operation. A more appropriate basis for evaluation of MAF projects is man-hours.

Military estimation systems generally assign man-hours or man-days to a task. Some manuals may use terms such as squad-day or platoon-week, but the conversion to man-hours is straightforward. Although some civilian construction estimation techniques result in a dollar estimate (e.g. the R.S. Means Building Construction Cost Data), in most cases it is not difficult to calculate man-hours from these figures since a labor/craft composition and wage rate are implicitly used.

The focus of interest in this methodology is to generate the daily scheduled rate of manpower for the operation. This is simply a straightforward summation of the daily effort required for each of the projects that occur during a particular day of the operation.

GENERAL EQUATIONS

To apply the methodology, the estimator must be able to assign a figure for the total effort needed to perform a project. In turn, the total project effort is a sum of the project sub-activity effort required for each of the projects that comprise an operation. The formula for total operation effort becomes:

$$CE(\text{Operation}) = \sum_{i=1} \sum_{j=1} T_{ij}$$

where CE = Construction Effort

T_{ij} = Daily construction effort for project that occurs on Day j

If this analysis is performed for all projects that make up the MAF operation a daily effort is available. Analysis of all projects at the sub-activity level is seldom possible during the preliminary planning. It is also not appropriate at the MAF Engineer level. This level of detail is far too time consuming. It will be performed at Batallion or Company level at a more detailed level. What is usually determined by MAF Engineer estimators is either the total effort required for the project of the individual operation or the total operation construction effort. The problem then becomes how to translate a total project construction effort into a daily effort. One method involves matching of characteristic curve shapes to the expected project expenditure of labor overtime.

CURVE ANALYSIS

Many construction projects, military or civilian, follow a handful of characteristic curve shapes. In curve analysis the area under a curve up to a certain point in time corresponds to the total construction effort up to that date (See Figure 1).

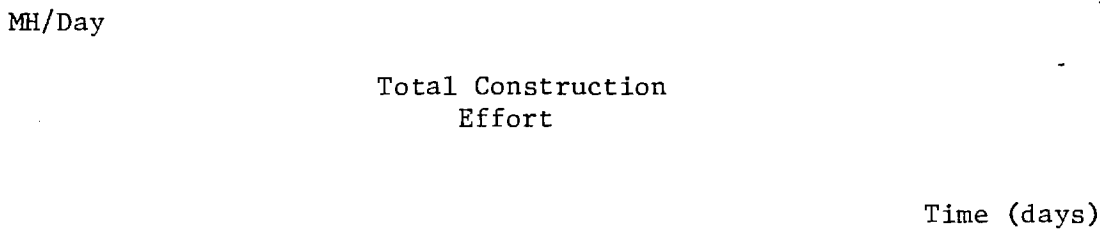


Figure 1: Daily Construction Effort Profile

When the total construction effort for a project is projected by an estimator the next step is to determine the shape of the curve of the manpower usage. Common curve shapes are:

Straight Line - This curve simply assumes a uniform, constant daily consumption of manpower. The daily manpower is obtained by dividing the total manhours required by the scheduled number of days for the project.

40% Peak

In this pattern labor usage builds up at a fairly constant rate until it peaks at 40% of the project duration and then declines a constant rate until the end of the project: (Figure 2)

Figure 2: 40% Peak Construction Effort Profile

67% Peak

This curve also builds at an increasing rate but committed labor peaks at about 2/3 of the way through the project duration (See Figure 3).

Labor
Rate

Time

Figure 3: 67% Peak Construction Effort Profile

85% Peak

In this type of project the labor usage builds up constantly until near the ned of the job when it drops off charply (See Figure 4).

Labor
Rate

Time

Figure 4: 85% Peak Construction Effort Profile

Peak in 15% and Continuous

This distribution will peak in about 15% of the project duration and maintain uniform distribution until about 85% when manpower will decrease to the end of the project (See Figure 5).

Labor
Usage

Time

Figure 5: Uniform Construction Effort Profile between 15% and 85%

CURVE COMPUTATIONS

At this point in a MAF operation, the projects that comprise the operation have been estimated for total man-hours and the projects have been identified for curve type. The task now at hand is to perform a numerical analysis for each curve to determine the day-by-day expenditure of labor. The drawback to this is that this analysis requires Gauss integration techniques. Fortunately , calculations have been performed for the above curves and require only the use of constants of integration. These constants of integration may be applied to any project whose labor distribution fits the above curves. This results in a period-by-period labor level. The remaining task is to sum labor figures for all projects of the MAF operation and compare this requirement to available manning levels. This type of analysis is ideally adapted to a computer program as is demonstrated in the Appendices.

SENSITIVITY ANALYSIS

Using the above methodology the engineer now has a view of the day-by-day labor requirement for the MAF operation and is able to compare these figures to availability of engineer labor resources. Projected shortfalls and surpluses can be readily identified and used as a basis for decision making. Such decisions may include: requesting additional engineer labor, shifting individual projects within the overall MAF schedule or adjusting individual project start/finish dates. This type of analysis is termed sensitivity analysis and is subject to external factors such as project priorities, tactical conditions or project interrelationships. With these factors in mind the engineer planners can go through an interative process of schedule adjustments that will drive them to a satisfactory solution. In the initial planning stages, much of the information may be tentative or ill-defined. It is relatively straightforward to perform this analysis in later stages when priorities become clearer and the tactical situation is more definitive.

SORTING

The analysis described above uses the overall project and gross labor availability as the basis of calculations. What if analysis is needed only for a certain area of the MAF operation, like the beach head or the base camp? If the projects of the MAF operation were further identified according to various criteria such as location or skill specialty, another dimension in the analysis can be added - sorting. Using a sort code for each project of the operation can completely specify the operation with regards to the work criteria. By specifying certain sort keys, calculations can be narrowed down to only those areas of interest. For example, if the engineer planners were interested in base camp labor requirements, only projects containing the base camp sort key would be analyzed. This provides a valuable new dimension in the analysis and allows a more detailed refinement to the labor solution for the MAF operation.

COMPUTER SYSTEM DESCRIPTION

In order to develop a better definition of the conceptual system described in the preceding sections, a prototype program was developed with the features identified. This prototype provides the basis for establishing a more precise specification to be used for further development of the system in the Tektronix 4052 environment. The program is activity oriented and is intended to be useful primarily during initial planning and evaluation of the MAF deployment. In order to maintain maximum flexibility in the sequencing of engineering tasks, the system does not utilize precedence relationships between activities. It is, therefore, not a network analysis system. It was felt that network techniques using more rigid logical relations among activities within projects was appropriate at a lower hierarchical level when and if precise planning data become available. Since this system is designed for use at the MAF engineer level the freedom of a more open-ended planning format was found more responsive to the planner's needs. Logic within the component projects which make up the operation is considered within the Engineering Management Topic described elsewhere.

The projects within the operation are considered as bars on a bar chart. In addition to HEADER information, available manpower and sorting request, the user inputs the following for each project:

(a) Line Number

(b) Activity Code

(c) Start Day

(d) Finish Day

(e) Manpower Consumption Curve

(f) Total Man-hours Required

These input items will be discussed in detail in the following paragraphs. After processing, the program outputs a day-by-day profile of the manpower needed. A comparison is made against the available manpower and the surplus or deficit for that day is displayed. The code for this prototype Manpower Forecasting Program is written in FORTRAN IV. It should be a straightforward task to convert it to BASIC or other higher-level language for use on a mini or micro computer.

PROGRAM INPUT

Header Information

This information simply tags a set of information to the computer run for identification purposes. It includes project number, name and date.

Project Information

The entire operation is considered to be a collection of projects or construction tasks. Information associated with each task is input line by line, project by project. The line of information consists of six items:

(1) Line Number - A two digit line number starting at 01 and increasing sequentially. For the prototype program described here the maximum number of projects is 99. Line number 00 signals end of input.

(2) Project Code - A four digit alpha-numeric character is used for sorting output reports. By specifying sorts based on different digits of the activity codes, a variety of useful reports can be generated. Although the four digits of the activity code may be used to represent any four levels desired by the user, it is recommended that the following scheme be followed.

   (a) First Digit - The entire operation itself should be reflected by entering the same digit in the first position for all projects. In this way an overall report may be output.

   (b) Second Digit - Identifies the engineer or support unit. Since more than one unit or different levels within the same unit (companies of a battalion, platoons of a company, etc.) would be involved in the operation, it would be useful to generate manpower reports about each unit for planning purposes.

(c) Third Digit - Area. The MAF operation could be broken down into zones, areas or districts.

(d) Fourth Digit - Project Designator. Individual projects in the MAF operation would be given a unique character.

(3) Project Start Day. The day numbering scheme centers around the concept of a D day or zero day. Thus, the earliest day a job may begin is on a day zero.

(4) Project Finish Day. The three digit finish day is also considered a day of work. Thus, the start-finish dates are an inclusive work period with no imbedded holidays.

(5) Project Curve. Between the start and finish of an activity, the manpower usage rate can be selected from several distribution patterns according to experience with similar activities in the past. The following patters are available:

Curve Code	Name	Note
01	Predistributed	This type of distribution would be used when the standard curves are not applicable and the user wants to assign man-hours to every day of the activity. Based either on a day by day input or a day by day percentage of the total.
02	Straight Line	Uniform distribution of man-hours from start to finish
03	40% Peak	Peak usage occurs at 40% of the time duration of the activity.
04	67% Peak	Same as 03 except 67%

Curve Code	Name	Note
05	85%	Same as 03 except 85%
06	Peak in 15% and continuous	This distribution will peak in about 15% of the time duration and maintain uniform distribution until 85% when manpower will decrease to the end of the activity.

(6) Man-hours. The total estimated man-hour effort for the activity is the last item to be entered for each activity.

Sort Request

The user now designates how activities should be organized for the output reports. Since there are four digits in the activity code, and the user may pick any combination of from one to four digits to sort upon, there exists up to 64 unique reports which may be printed. Only the digits from one to four may be chosen. Anyother would not make sense. Forexample, to output reports based on engineer unit by area, the sort keys of 2 and 3 would be entered.

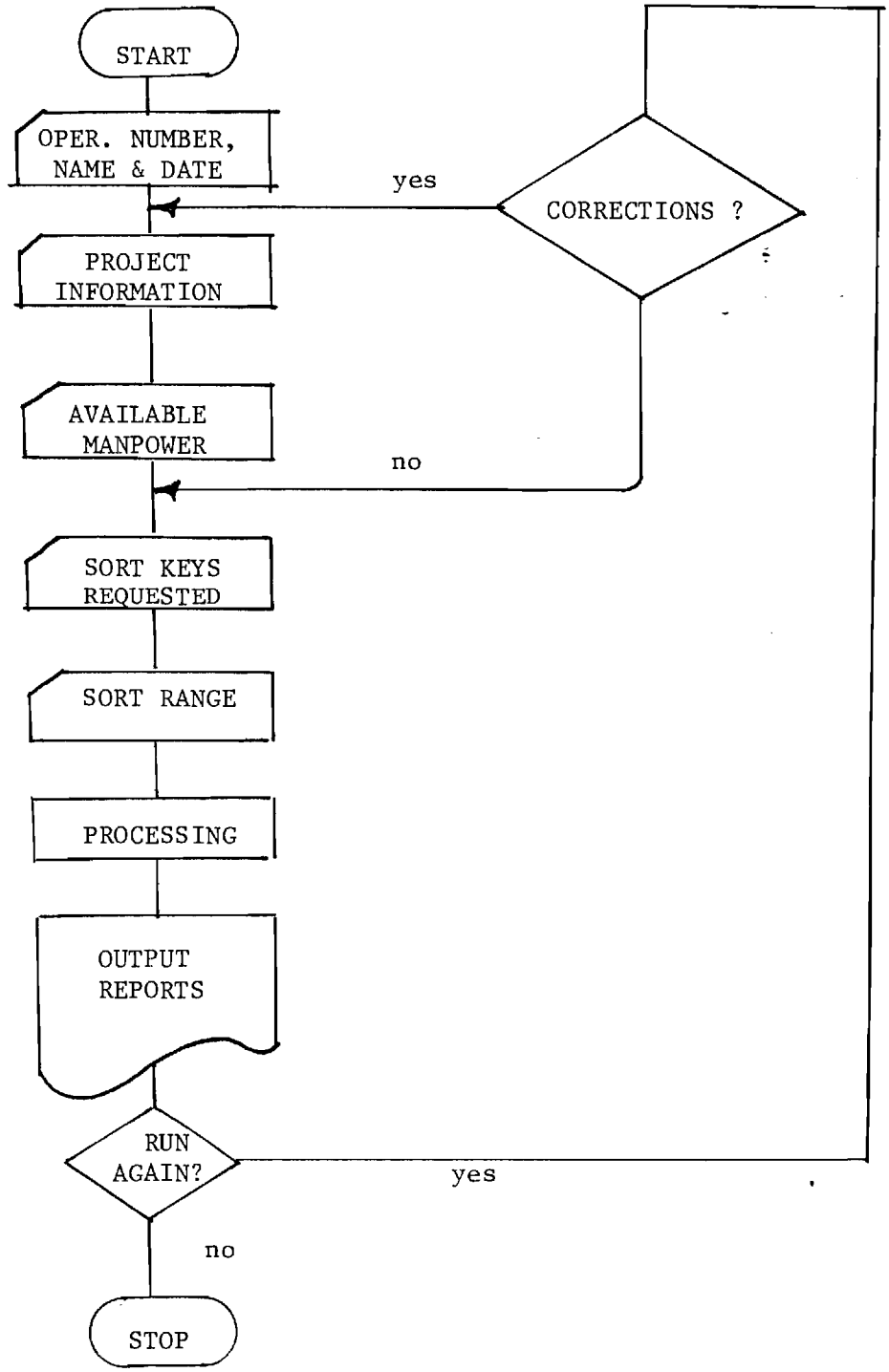
Activity Range

Only a specified range of activities may be chosen for analysis by the activity range. The range is given by a lower and upper boundary.

A flow chart of the input sequence is given in Figure 6.

Figure 6: Program Input

Macro Flow Chart



PROGRAM PROCESSING

The following is a general sequence of steps followed by the program. It skips over many trivial intermediate steps to cover the important ones in sequential fashion.

(1) Information about each activity is loaded into a two-dimensional array called ITABLE. Each row of ITABLE corresponds to a separate project of the operation. The rows of the array are referenced by the line number. The correction routine keys on the line number also.

(2) By calling a subroutine called RANGE, the project is checked to see if it is in the "range". That is, it is checked to see if its project code is greater or equal to the lower range value and it is less than or equal to the upper range value. If an activity is not in the range it is not considered.

(3) If the range condition for an activity is met, the program calculates the daily expenditure of man-hours. Six types of cases are considered depending on the curve. For the predetermined case it is already done. For the uniform case it is essentially done except for a simple percentage operation. The four remaining curve types require Gauss Quadrature Integration. Specific constants of integration (stored in array POLCO) are needed for each curve. In creating the daily manpower values, a large array called IRETA is used. A row is created in IRETA for each activity that is in range. It has in each row the following: sort keys (activity code), day and man-hours (for that day).

(4) The IRETA array is next subjected to a sorting operation. The

IRETA array is placed in sorted order by suing a "bubble sorting" procedure. The order is according to the wort keys that the program user specified.

(5) With IRETA now sorted, the information is now ready to be summed and output. First, however, the header lines containing the ID data, page, etc. is output by a subroutine called HEADING. Another subroutine called WRLIN does the summing on a day by day basis and prints the results when a change in the day is found. The procedure is repeated until the IRETA array is depleted.

(6) This graphical output is the last part for every report. The basic technique is carried out by scaling the appropriate height to correspond to manpower and length to time.

(7) By responding to prompting statements the user can rerun the same data, change the same data or run new networks. When rerunning the same data, the program maintains the ITABLE array so it can be used again for range check and building a new IRETA array.

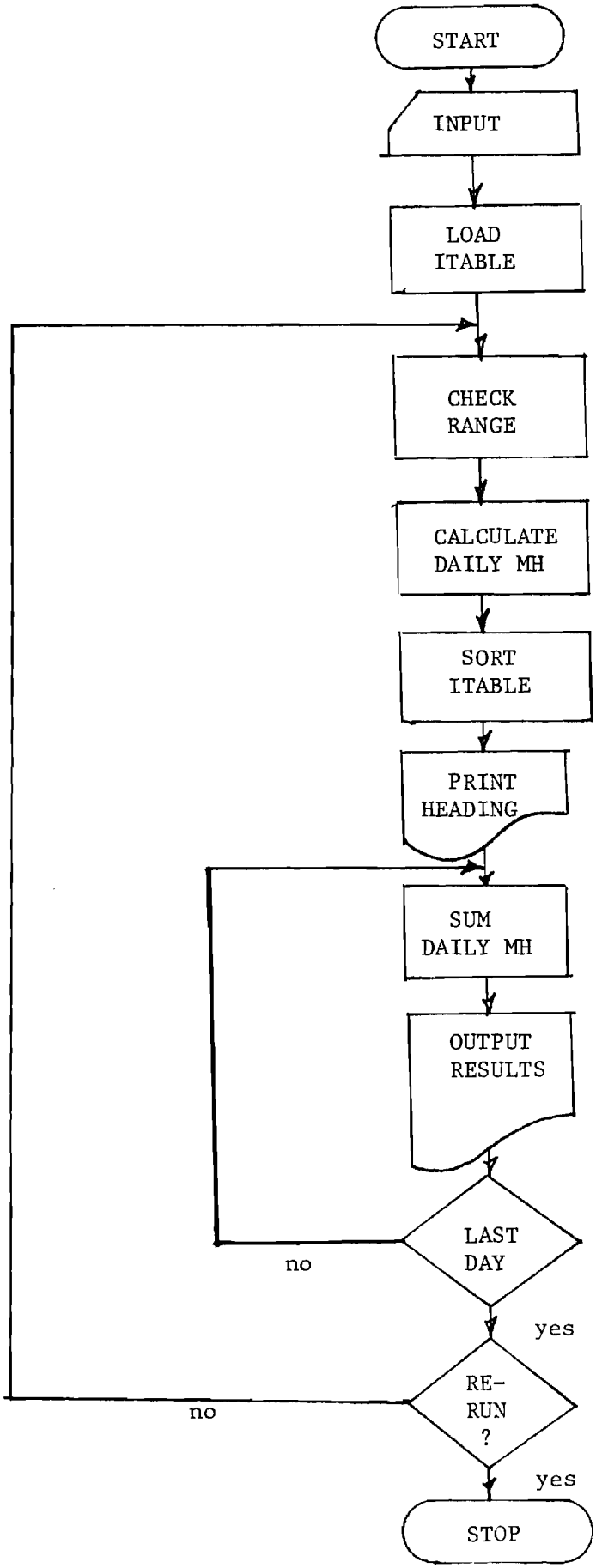
The important arrays and their contents are as follows:

ITABLE		IDIRE	
1-4	Project Code	1	Line Number
5	Start Day	2-5	Project Code
6	Finish Day	6	Day
7	Curve	7	Percent
8	Man-hours	8	Man-hours

KRETA		IRETA	
1-4	Project Code	1-4	Project Code
5	Day	5	Day
6	Man-hours	6	Man-hours

The sequence of functions performed during processing is given in Figure 7.

Figure 7: Program Processing
Macro Flow Chart



PROGRAM OUTPUT

An example of the interactive input-output sequence is given in Appendix A. Output is geared toward a day by day summary of projected manpower over the duration of the operation. Each output of the run is based on the sort keys selected by the planner. The program outputs as many reports in one run as there are unique sort keys. Virtually dozens of reports are possible if a rich variety of project codes are used. A recommended starting place is to generate one overall report first. This can always be produced if the sort key of 0 (zero) is used. This is the one time a sort key other than the sort key designators 1 through 4 should be used. The overall report is a good starting place to analyze the scope of the operation. By successively applying corrections and making changes, a balanced manpower profile can be designed. Thus, if the estimate is fairly reliable and the manpower is consistent with expectations, an intelligent plan can be relied upon instead of guesswork. Changes made during intermediate stages of the operation should be no problem if the program is rerun with the new or revised data. The initial plan is just that initial. Changes are inevitable!

EXAMPLE OPERATION

A simulated MAF operation has been planned for an area in the vicinity of Ft. Belvoir, Virginia. See the enclosed maps. A 1:25,000 scale map and aerial photograph show the general area of operations. An enlarged map and aerial photograph show the general area of operations. An enlarged map of the area around Davidson Airfield adjacent to Ft. Belvoir shows the general layout of the proposed engineer tasks. Initial estimates have been developed for operation related projects as well as proposed start and finish dates that coincide with the overall objectives of the MAF operation. These estimates and schedule dates are given in Table 1. The initial engineer manpower assets consists of one Marine combat engineer battalion supported by two company sized units with specialized vertical and horizontal construction skills. In addition, the engineers are supported by a full complement of maintenance and support personnel. Construction effort available to the combat battalion is about 4500 man-hours per day and the specialized units have about 2300 available man-hours per day. The project coding scheme has been followed as discussed previously: a common first digit corresponding to the MAF operation, two unique second digits for the two units, the third digit has been broken down to correspond to various areas, and the fourth digit is unique for each job or task to be performed. Using the manpower forecasting program the adequacy of the engineer support can be compared to the proposed construction schedule.

A time scheduled diagram of the initial schedule for projects within the operation is given in Figure 8.

Table 1: Estimated Man-hours and Schedule Dates for MAF Operation

MAF WORK PROJECTS	Man-hours	St/Fin Dates (Day)	Code
1. Camp Construction			
a. Elec Svcs	7750	12-23	0211
b. Structures	98000	7-28	0112
c. Hygenic Svcs	4500	9-15	0213
2. Fuel and Distribution System			
a. POL tanks (type A)	16500	15-26	0224
b. POL tanks (type B)	18500	19-41	0225
c. Pumping Station	7800	17-40	0226
d. Admin Bldg	850	23-27	0127
3. Potable Water Supply	450	3-8	0238
4. Road Construction	17000	15-23	0149
5. Timber Bridge	2900	21-29	013A
6. Expeditionary Airfield			
a. Earthwork	8900	0-14	015B
b. Matting	13400	10-15	015C
c. Revetments	6800	0-15	015D
d. Paved Areas	14300	8-19	015E
7. Obstacles/Barrier Plan			
a. Craters	780	0-5	016F
b. Minefield	240	2-7	016G
c. Standard Obstacles	1350	0-10	016H

Code: 1st Digit MAF Operation
2nd Digit Unit-1 or 2 Cbt Engr (1), Const Unit (2)
3rd Digit Area-1 Camp, 2 POL, 3 River, 4 Road, 5 Airfield, 6 Other
4th Digit Job - All unique

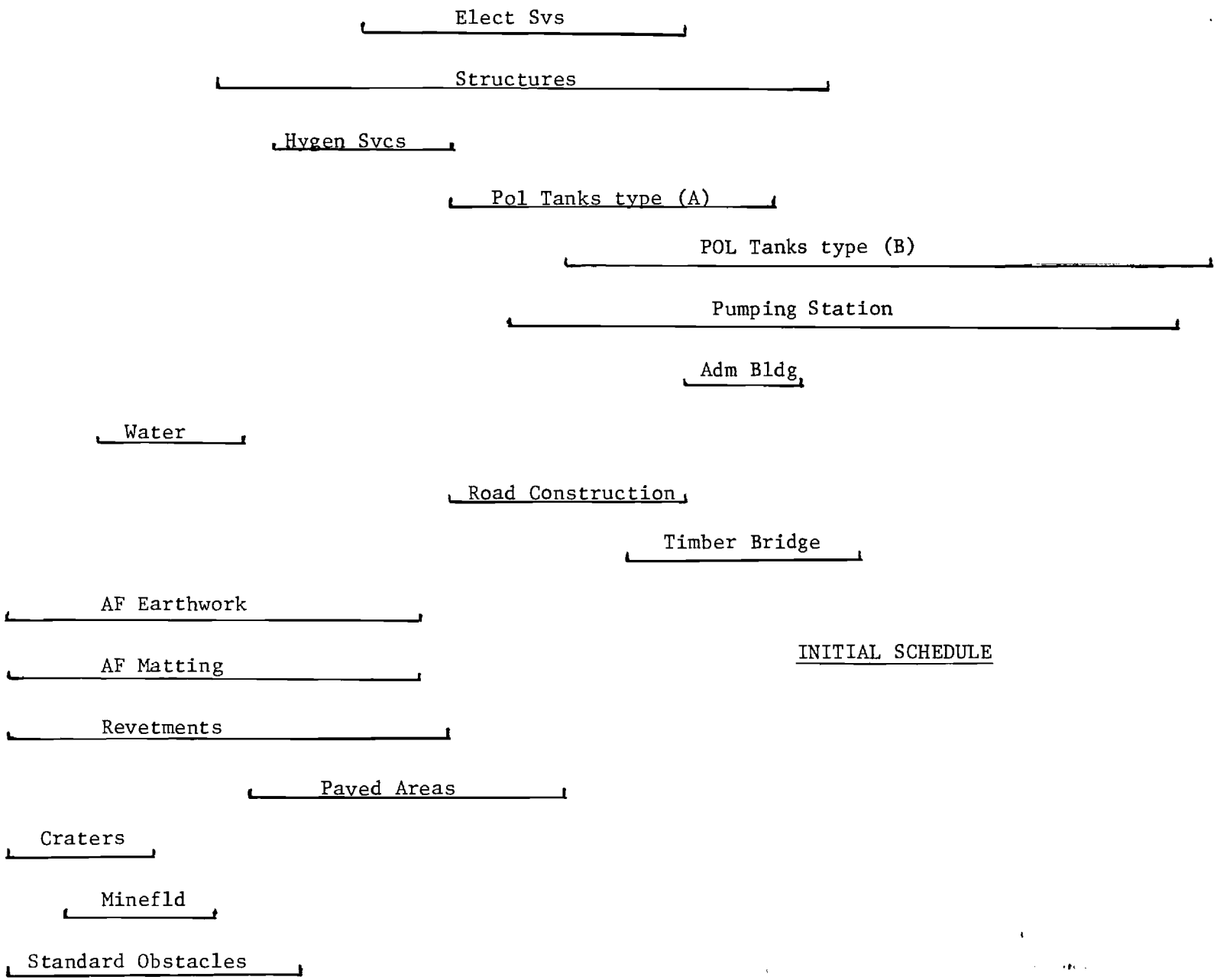


Figure 8: Initial Schedule for MAF Operation

ANALYSIS OF THE EXAMPLE MAF OPERATION

The run of the initial schedule for the operation is shown in Table 2. Graphical output from the prototype program is shown in Fibure 9. Obviously the initial schedule is unbalanced during day 11 to 22. This is in spite of the fact that scheduled activities account for only about 80% of the available manpower. The planners now have to look at the individual activities and make decisions about rescheduling start and/or finish dates. This must be done within the scope and objectives of the MAF operation. After this was done, and the individual activities shifted, another run of the program was made. This run is presented in Table 3 and shows a much more balanced and feasible situation although there is still room for improvement if MAF objectives allow shifting of activity dates. Further refinement (not shown) is also possible by considering the schedule and available manpower within each of the two engineer units. When this stage is completed, a feasible schedule is available. At this stage a myriad of reports can be generated. Examples are: manpower sorted by area, by individual activity, by unit and by area, etc. These reports could be useful at various echelons within the MAF.

HOURS VS TIME CURVE

Figure 9. GRAPHICAL OUTPUT - INTIAL RUN

* * * = AVAILABLE MH.
\+ + + = REQUIRE MH.

IF AVAILABLE MH. DATA DOES NOT APPEAR IN THE PLOT THIS
MEANS THAT THIS DATA IS TOO LARGE AND CAN NOT BE SCALED.

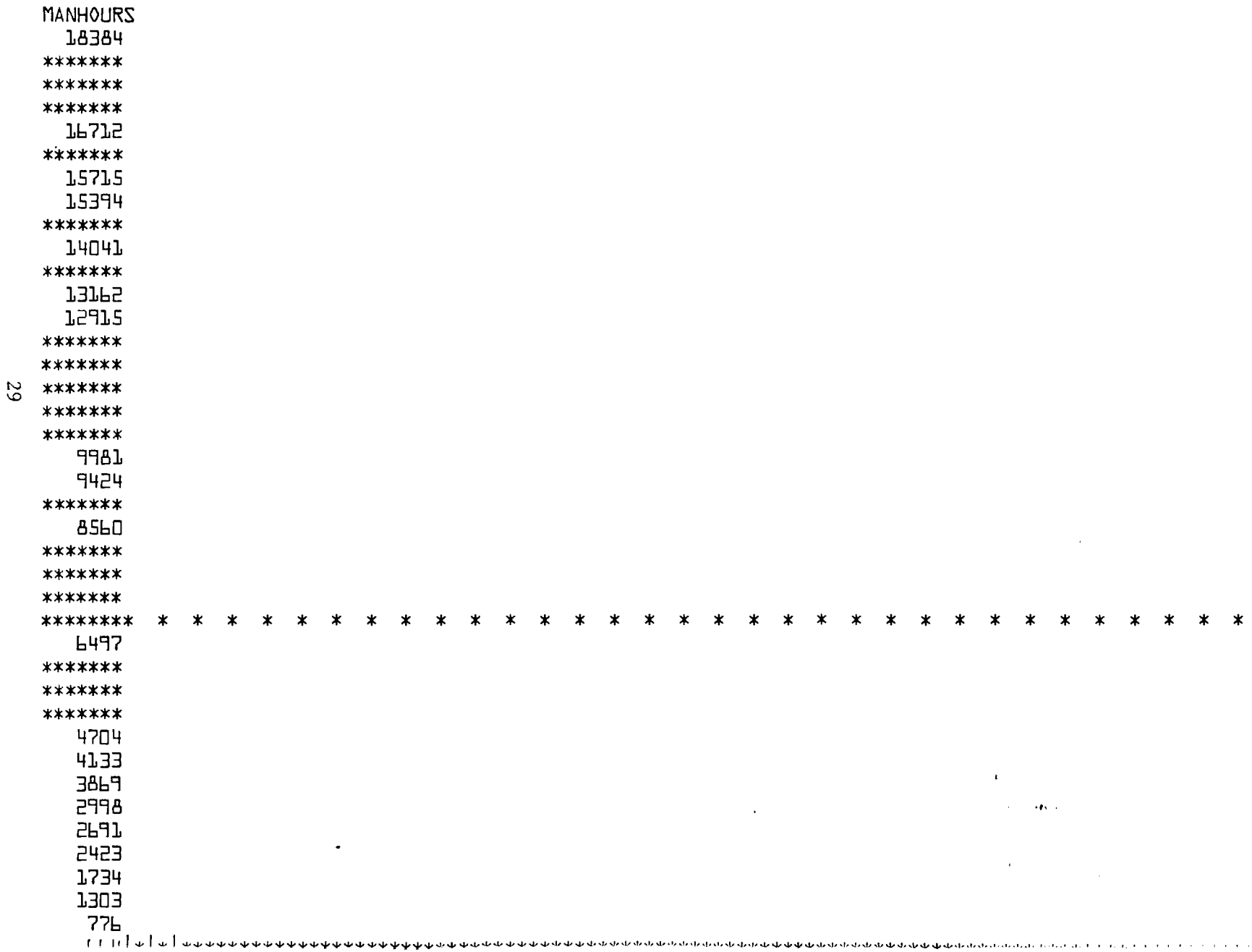


Figure 10 - GRAPHICAL OUTPUT - SECOND RUN

```
     * * * = AVAILABLE MH.
     + + + = REQUIRE MH.          IF AVAILABLE MH. DATA DOES NOT APPEAR IN THE PLOT
                                MEANS THAT THIS DATA IS TOO LARGE AND CAN NOT BE SCALE.

MANHOURS
   6659
   6523
   6287
   6155
   5947
   5779
   5665
   5546
   5360
   5175
   5020
*******
*******
   4439
*******
*******
   4005
   3757
*******
   3538
*******
*******
   2953
*******
   2739
   2414
   2254
*******
*******
*******
*******
*******
*******
*******
*******
*******
*******
*******
*******
**************************************************************************************************************************
```

Table 2

INITIAL RUN

MAF OPERATION OPERATION 123-3 DATE 12-25-80

PROJECT CONTROL FORECAST MAN HOURS SYSTEM

MANOURS FOR DAY	MANHOURS	CUM. MANHOURS	AVAL. MANHOURS	SURPLUS OR DEFICIT
0	285.	285.	6800.	6515.
1	445.	730.	6800.	6355.
2	664.	1394.	6800.	6136.
3	1600.	2994.	6800.	5200.
4	1770.	4764.	6800.	5030.
5	1893.	6657.	6800.	4907.
6	1813.	8470.	6800.	4987.
7	2998.	11468.	6800.	3802.
8	3869.	15337.	6800.	2931.
9	4787.	20124.	6800.	2013.
10	6325.	26449.	6800.	475.
11	8701.	35150.	6800.	-1901.
12	12739.	47889.	6800.	-5939.
13	15715.	63604.	6800.	-8915.
14	16712.	80316.	6800.	-9912.
15	12915.	93231.	6800.	-6115.
16	13162.	106393.	6800.	-6362.
17	14041.	120434.	6800.	-7241.
18	15394.	135828.	6800.	-8594.
19	18384.	154212.	6800.	-11584.
20	9981.	164193.	6800.	-3181.
21	9424.	173617.	6800.	-2624.
22	8560.	182177.	6800.	-1760.
23	6497.	188674.	6800.	303.
24	4704.	193378.	6800.	2096.
25	4133.	197511.	6800.	2667.
26	2691.	200202.	6800.	4109.
27	2033.	202235.	6800.	4767.
28	2423.	204658.	6800.	4377.
29	1736.	206394.	6800.	5064.
30	1594.	207988.	6800.	5206.
31	1751.	209739.	6800.	5049.
32	1868.	211607.	6800.	4932.
33	1933.	213540.	6800.	4867.
34	1935.	215475.	6800.	4865.
35	1868.	215343.	6800.	4932.
36	1734.	219077.	6800.	5066.
37	1541.	220618.	6800.	5259.
38	1303.	221921.	6800.	5497.
39	1040.	222961.	6800.	5760.
40	776.	223737.	6800.	6024.
41	208.	223945.	6800.	6592.

Table 2

SECOND RUN

MAF OPERATION OPERATION 123-3 DATE 12-25-80

PROJECT CONTROL FORECAST MAN HOURS SYSTEM

MANHOURS FOR 0 DAY	MANHOURS	CUM. MANHOURS	AVAL. MANHOURS	SURPLUS OR DEFICIT
0	2254.	2254.	6800.	4546.
1	2414.	4668.	6800.	4386.
2	2594.	7262.	6800.	4206.
3	2953.	10215.	6800.	3847.
4	3538.	13753.	6800.	3262.
5	4439.	18192.	6800.	2361.
6	5439.	23631.	6800.	1361.
7	5560.	29191.	6800.	1240.
8	6461.	35652.	6800.	339.
9	5732.	41384.	6800.	1068.
10	4005.	45389.	6800.	2795.
11	2739.	48128.	6800.	4061.
12	5919.	54047.	6800.	881.
13	5839.	59886.	6800.	961.
14	5759.	65645.	6800.	1041.
15	5118.	70763.	6800.	1682.
16	6002.	76765.	6800.	798.
17	6326.	83091.	6800.	474.
18	6326.	89417.	6800.	474.
19	6331.	95748.	6800.	469.
20	5175.	100923.	6800.	1625.
21	5546.	106469.	6800.	1254.
22	5604.	112073.	6800.	1196.
23	5675.	117748.	6800.	1125.
24	5764.	123512.	6800.	1036.
25	5879.	129391.	6800.	921.
26	6523.	13514.	6800.	277.
27	5779.	141693.	6800.	1021.
28	6659.	148352.	6800.	141.
29	6181.	154533.	6800	619.
30	6015.	160548	6800.	785.
31	6175.	166723.	6800.	625.
32	6303.	173026.	6800.	497.
33	6366.	179392.	6800.	434.
34	6357.	185749.	6800.	443.
35	6287.	192036.	6800.	513.
36	6155.	198191.	6800.	645.
37	5947.	204138.	6800.	853.
38	5665.	209803.	6800.	1135.
39	5360.	215163.	6800.	1440.
40	5020.	220183.	6800.	1780.
41	3757.	223940.	6800.	3043.

CONCLUSIONS

Based on the development of the prototype planning and estimating program and the demonstration problem presented, certain conclusions appear to be supported:

(1) It is possible to define a logical and systematic format which is flexible enough to schedule the construction projects inherent in the development of an AOA. This system using limited data allows the efficient and logical utilization of manpower and other resources for which requirements and availability can be defined in a manner similar to that used in the prototype system.

(2) The proposed methodology may be applied at different stages in the planning process as guidelines become increasingly definitive. Accordingly, results become more precise.

(3) Comparative data, arrived at in a sound, systematic manner may be presented to the commander or other decision making individuals providing the basis for sound decisions.

(4) A finer level of detail results from the use of a well-devised sorting code.

(5) The computer system described in the System Description Sections and Appendices A and B can be adapted to other computers such to include microcomputer graphics oriented systems such as the Textronix 4052.

The computer program as described in the appendicies is implemented on a large, host computer (CDC CYBER 70) in the FORTRAN porgramming language.

As presently configured, the prototype program is not transportable to smaller mini or micro computers. This program was written primarily to define a conceptual framework. One problem in implementing this program in the microcomputer environment is computer word size. The CYBER machine used to develop the prototype has a 60 bit word and a 6 bit character byte. Precision and character data would be affected on machines with smaller word size. Also, the predominant computer language for smaller computers is BASIC as opposed to FORTRAN. The two programming languages are very similar so it should be a straightforward task for a skilled programmer to convert the present program to BASIC.

The methodology described herein is applied only to the resource of labor. The concept could also be extended to other resources. The output to the planner is a resource usage over time, i.e. a resource usage rate. The concept could be extended to other resources as well. For example, the logistical requirements for construction demand specific cubages of materials by a specific schedule. The ramifications are the same if the resource demand exceeds the supply - the schedule is not met and delays result. Proper analysis could insure usable loading plans and shipping schedules.

The explosion of computer graphics techniques within the last five years has led to the development of many easy to use display devices and software packages. The idea of projecting a graphic display of resources is attractive and is an appropriate extension of the prototype presented. With these systems not only static displays are possible but interactive manipulation of schedule using light pens and similar devices is possible. Intelligent programs have already been developed to accept graphic input to drive.

Optimization techniques using light pen or joy programs. Stick input to initiate solution sequences is a possibility. It may be better, however, at this stage of development to rely upon a "heuristic" optimization on the part of the planner. This user interaction approach allows an interaction of qualitative factors known to the planner which override the quantitative considerations inherent in rigorously optimal solution techniques.

APPENDIX A

On Line Session with MAF Manpower Forecasting Program

The prototype computer program was developed in FORTRAN IV computer language and implemented on the CDC CYBER 74 Computer. This demonstration follows a step by step process. The explanations to the steps are contained in the boxes. Before proceeding as shown below the user must log on the machine.

Step No. 1 After logging on, the manpower program must be brought in from disk (not shown). Below, the FTNTS stipulates the FORTRAN time-sharing system. The command RUN compiles and executes the program.

```
FTNTS
READY.
RUN

80/08/19. 19.35.18.
PROGRAM   PILA
```

Step No. 2 After printing a brief program description, the following heading information is requested:

- Operation Number. Ten alpha-numeric characters are allowed.
- Operation Name. Up to 40 alpha-numeric characters allowed.
- Date of Report. Example 02-15-80 would be 15 Feb 1980.

```
                MANPOWER FORECASTING PROGRAM

 PROGRAM IS USED FOR FORECASTING LABOR REQUIREMENTS
 ENTER OPERATION NUMBER
? 1123
 NAME OF OPERATION
? EXAMPLE
 DATE OF THE REPORT IN THE FORM 99-99-99 MO,DY,YR

? 12-15-80
```

Step No. 3 The program accepts input from a disk file which would have been created earlier. The format of this file would conform to the same format as data input to the terminal in the interactive mode. If the reply to the prompting question is NO, the program expects the data to be input from the terminal. If the answer is YES, the input file is read.

```
 DO YOU HAVE FILE INPUT YES, NO
? NO
```

Step No. 4 For each and every project in the MAF operation enter the required information as previously discussed. The first two digits in the input stream is a line number used primarily for identification/modification purposes. This number should start at 01 and increase sequentially. If an error is made during this phase of input, it can be corrected in a following step. In the example below the character "9" designates that a numeric character is required, character "X" means alpha-numeric. To end this phase of input enter a 00 (zero zero) as a line number and press the RETURN key.

```
ENTER PROJECTS IN THE FOLLOWING SEQUENCE

LINE NO.**PROJ. NO.**START DAY**END DAY**CURVE**HOURS**

 =99 XXXX 999 999 99 9999999
? 01 0122 000 009 02    4600
? 02 0233 010 024 03    7800
? 03 0322 012 020 04    3200
? 04 0211 005 024 06    1300
? 05 0312 014 021 02     300
? 00
```

Step No. 5 The daily available man-hours are entered in this step. This may be broken up into as many segments as desired. Again, to end the input stream a 00 line number is entered.

```
  INPUT YOUR AVAILABLE MANHOURS  IN THE
FOLLOWING WAY: LINE *-START DAY-END DAY-MANHOURS AVAL.
 =99 999 999 9999999

? 01  000 014    600
? 02  015 024    800
? 00
```

Step No. 6 Here the input may be reviewed for accuracy.

```
END OF INPUT
WOULD YOU LIKE TO PRINT INPUT TABLE YES, NO

YES


**** PROJECT INFORMATION ****

1 0122   0    9   2   4600
2 0233  10   24   3   7800
3 0322  12   20   4   3200
4 0211   5   24   6  13000
5 0312  14   21   2   3000

**** AVAILABLE MANHOURS INFORMATION ****

1    0    14       600
2   15    24       800
```

Step No. 7 The user is able to enter the corrections routine by entering a YES reply. This would be useful for correcting errors as well as performing sensitivity analysis after an initial output has been analyzed. If the user entered a YES reply the program returns to step 6 (print table) to verify corrections.

```
 WOULD YOU LIKE TO MAKE CORRECTION YES, NO
? YES


 *** IMPORTANT **
 IF YOU MAKE CORRECTIONS TO DISTRIBUTED RECORDS YOU CAN ADD OR
 SUBTRACT FROM EXISTING RECORDS
 TO MAKE A CHANGE


 *** CORRECTIONS FOR ACTIVITY INFORMATION ***

   TO CORRECT ANY LINE, TYPE THE LINE COMPLETELY
  INCLUDING THE LINE NUMBER.  TO END TYPE 00 UNDER LINE
  =99 XXXX 999 999 99 9999999
? 05 0312 010 024 02    2500
? 00

 *** CORRECTIONS FOR AVAILABLE MANHOURS INFORMATION ***

 TO CORRECT ANY LINE, TYPE THE LINE COMPLETELY INCLUDING THE LINE NUMBER.
 TO END TYPE 00 UNDER THE LINE NUMBER
  =99 999 999 9999999
? 02 0L5 024     700
? 00
```

Step No. 8 In the final input step before the output, the user can specify how the output is to be sorted by entering two types of sorting parameters. The first specifies which digit or digits of the activity is to be sorted. The second is the range of the activity code to be sorted. Here an upper and lower bound are entered. Output follows.

```
 ENTER REPORT REQUEST PARAMETERS
 EXAMPLE FOR SOR PARAMETERS
 1,2      REPORT WILL BE SORTED AND SUMMARIZED BY SECOND AND
          FIRST DIGIT OF THE ACTIVITY NUMBER

 1,2,3,4 REPORT WILL BE SORTED AND SUMMARIZED BY FIRST
          SEDOND, THIRD AND FOURTH DIGIT OF THE ACTIVITY NUMBER

 SORTED BY
? 1
 ACTIVITY RANGE -- FROM
? 0000
 TO
? 9999
```

PAGE NO. 1

MAF OPERATION OPERATION 1123 DATE 12-25-80

PROJECT CONTROL FORECAST MAN HOURS SYSTEM

MANHOURS FOR 0 DAY	MANHOURS	CUM. MANHOURS	AVAL. MANHOURS	SURPLUS OR DEFICIT
0	459.	459.	600.	141.
1	459.	918.	600.	141.
2	459.	1377.	600.	141.
3	459.	1836.	600.	141.
4	459.	2295.	600.	141.
5	687.	2982.	600.	-87.
6	976.	3958.	600.	-376.
7	1152.	5110.	600.	-552.
8	1206.	6316.	600.	-606.
9	1201.	7517.	600.	-601.
10	1089.	8606.	600.	-489.
11	1274.	9880.	600.	-674.
12	1509.	11389.	600.	-909.
13	1766.	13155.	600.	-1166.
14	2018.	15173.	600.	-1418.
15	2262.	17435.	700.	-1562.
16	2432.	19867.	700.	-1732.
17	2438.	22305.	700.	-1738.
18	2218.	24523.	700.	-1518.
19	1812.	26335.	700.	-1112.
20	1366.	27701.	700.	-666.
21	1136.	28837.	700.	-436.
22	1013.	29850.	700.	-313.
23	838.	30688.	700.	-138.
24	368.	31056.	700.	332.

```
 WOULD YOU LIKE TO RUN ANOTHER REPORT YES, NO
? NO

 SRU   13.420 UNTS.

 RUN COMPLETE.
```

APPENDIX B

PROGRAM LISTING

```
0005        PROGRAM MNR(INPUT,OUTPUT,DATA,
0010+       TAPE5=INPUT,TAPE6=OUTPUT,TAPE1=DATA)
0030        DIMENSION ITABLE(99,13),IT(13),TITLE(12),IDIRE(10)
0040      DIMENSION NDIS(180,3),ADIS(180),POLCO(4,10)
0050        DIMENSION KRETA(500,8)
0060        DIMENSION IRETA(1000,8),ISTO(8),VAST(18)
0070        INTEGER AA,AYES,ANO,DM,DD,DY
0080        INTEGER A(4),B(4),SK(4)
0084        INTEGER PR1,PR2
0090        EQUIVALENCE (NL,NLINE)
0100        DATA AST/"*****"/
0110        DATA AYES/"YES"/,ANO/"NO"/,IBL/" "/
0120C       40% CURVE
0130        DATA(POLCO(1,K),K=1,10)/4.769723,18.87661,7.186824,-1.69471,
0140+       .4767295,-.256268,.0527045,-.004477,.0001371,0./
0150C       67% CURVE
0160        DATA(POLCO(2,K),K=1,10)/.2566663,-3.904401,12.18992,-7.215445,
0170+       2.4349,-.3848893,.0273482,-.000716,0.,0./
0180C     ....85% CURVE
0190        DATA(POLCO(3,K),K=1,10)/.9763276,11.07774,-33.31818,46.37876,
0200+       -27.08342,8.527045,-1.549136,.1620897,-.00090576,.000209/
0210C     .....15% CURVE
0220        DATA(POLCO(4,K),K=1,10)/15.27915,-55.105,276.109,-254.9308,
0230+       114.699,-29.70904,4.650124,-.434715,.0223552,-.0004867/
0240        NRR=0
0250        NRX=0
0260        PRINT 800
0270  800   FORMAT(1X,//1X,T10,"PROJECT CONTROL FORECAST SYSTEM"/1X,
0280+       T10,"DANIEL INTERNATIONAL CORPORATION"//)
0290        PRINT 801
0300  801   FORMAT(1X,"PROGRAM IS USED FOR FORECASTING LABOR REQUIREMENTS",
```

```
0310+       /1X,"FOR CONSTRUCTION PROJECTS"//)
0320        PRINT 802
0330  802   FORMAT(1X,"ENTER PROJECT NUMBER")
0340        READ 862,PR1,PR2
0350  862   FORMAT(A4,A2)
0360        PRINT 803
0370  803   FORMAT(1X,"NAME OF THE PROJECT")
0380        READ 861,(TITLE(J),J=1,12)
0390 861    FORMAT(12A4)
0400        PRINT 804
0410        DO  871 J=1,99
0420        DO  873 JJ=1,4
0430        ITABLE(J,JJ)=IBL
0440  873   CONTINUE
0450        DO  874 JJ=5,13
0460        ITABLE(J,JJ)=0
0470  874   CONTINUE
0480  871   CONTINUE
0490  804   FORMAT(1X,"DATE OF THE REPORT IN THE FORM 99-99-99 MO,DY,YR"//)
0500        READ 805,DM,DD,DY
0510  433   PRINT 430
0520  430   FORMAT(1X,"DO YOU HAVE FILE INPUT YES, NO")
0530        READ 870,AA
0540        IF(AA.EQ.ANO) GO TO 431
0550        IF(AA.EQ.AYES) GO TO 432
0560        GO TO 433
0570  432   CALL REFIL(ITABLE,NRR,IRETA)
0580        NRX=NRR
0590        GO TO 820
0600  805   FORMAT(3(I2,1X))
0610  431   PRINT 806
0620  806   FORMAT(1X,"ENTER ACTIVITIES IN THE FOLLOWING SEQUENCE"/)
```

```
0630        PRINT 807
0640   807  FORMAT(1X,"LINE NO.**ACTIV. NO.**START DATE**END DATE**CURVE**",
0650+       "HOURS**COST**"/)
0660        PRINT 808
0670   808  FORMAT(1X,"=99",1X,"XXXX",1X,"99-99-99",1X,"99-99-99",1X,"99",1X,
0680+       "9999999",1X,"99999999")
0690   840  READ 863,NCX,(IT(J),J=1,13)
0700   863  FORMAT(I2,1X,4A1,1X,7(I2,1X),I7,1X,I8)
0710        IF(NCX.EQ.0)GO TO 820
0720        IF(NCX.GT.99) GO TO 825
0730        IF(IT(11).EQ.1) GO TO 872
0740        DO 810 K=1,13
0750        ITABLE(NCX,K)=IT(K)
0760   810  CONTINUE
0770        GO TO840
0780   820  PRINT 815
0790   815  FORMAT(1X,"END OF INFUT")
0800   818  PRINT 816
0810   816  FORMAT(1X,"WOULD YOU LIKE TO PRINT INPUT TABLE YES, NO"/)
0820        READ 870,AA
0830        IF(AA.EQ.ANO) GO TO 835
0840        IF(AA.EQ.AYES) GO TO 832
0850        GO TO 818
0860   832  DO 841  K=1,99
0870        IF(ITABLE(K,1).EQ.IBL) GO TO 841
0880        WRITE (6,850)K,(ITABLE(K,J),J=1,13)
0890   850  FORMAT(1X,I2,1X,4A1,1X,I2,"-",I2,"-",I2,1X,I2,"-",I2,"-",I2,
0900+       1X,I2,1X,I7,1X,I8)
0910   841  CONTINUE
0920   835  PRINT 846
0930   846  FORMAT(1X,"WCULD YOU LIKE TO MAKE CORRECTION YES, NO")
0940   852  READ 870,AA
```

```
0950        IF(AA.EQ.ANO) GO TO 851
0960        IF(AA.EQ.AYES) GO TO 896
0970        GO TO 852
0980   825  PRINT 860
0990   860  FORMAT(1X,"NUMBER OF ACTIVITIES MUST BE LESS THAN 99, IF YOUR",
1000+       "INPUT IS COMPLETE ENTER 0 AS A LINE NUMBER"/)
1010        GO TO 840
1020   896  PRINT 831
1030   831  FORMAT(1X,"***  IMPORTANT  ***"/1X,"IF YOU MAKE CORRECTIONS TO",
1040+       " DISTRIBUED RECORDS YOU CAN ADD"/1X,"OR SUBTRACT FROM EXISTING",
1050+       "RECORDS"/1X,"TO MAKE A CHANGE"/)
1060        GO TO 840
1070   870  FORMAT(A4)
1080C ...READ DISTRIBUTED RECORD
1090C ...
1100   872 WRITE(6,875)
1110   875  FORMAT(1X,"ENTER DISTRIBUTED RECORDS IN THE FOLLOWING SEQUENCE")
1120       WRITE(6,877)
1130   877  FORMAT(1X,"LINE NO.**ACTIV. NO.**MONTH**YEAR**PERCENT**MANHOURS",
1140+       "**COST**")
1150        WRITE(6,878)
1160   878  FORMAT(1X,"=99 XXXX 99 99 99 9999999 99999999")
1170   882  READ 879, (IDIRE(J),J=1,10)
1180   879  FORMAT(I2,1X,4A1,1X,3(I2,1X),I7,1X,I8)
1190        IF(IDIRE(1).EQ.0) GO TO 840
1200        NRX=NRX+1
1210        DO 881 K=1,4
1220        L=K+1
1230        KRETA(NRX,K)=IDIRE(L)
1240   881  CONTINUE
1250        KRETA(NRX,5)=IDIRE(6)
1260        KRETA(NRX,6)=IDIRE(7)
```

```
      IF(IDIRE(8).EQ.0) GOTO 880
C.....PERCENT GIVEN
      AS=IDIRE(8)/100.
      KRETA(NRX,7)=IT(12)*AS
      KRETA(NRX,8)=IT(13)*AS
      GO TO 882
C....ACTUAL VALUES GIVEN
  880 KRETA(NRX,7)=IDIRE(9)
      KRETA(NRX,8)=IDIRE(10)
      GO TO 882
C.....READ REPORT REQUEST RECORD
  851 PRINT 885
  885 FORMAT(1X,///1X,"ENTER REPORT REQUEST PARAMETERS")
      PRINT 886
  886 FORMAT(1X,"EXAMPLE FOR SORT PARAMETERS"/1X,
     +    "1,2     REPORT WILL BE SORTED AND SUMMARIZED BY SECOND AND"/1X,
     +    "        FIRST DIGIT OF THE ACTIVITY NUMBER"//1X,
     +    "1,2,3,4 REPORT WILL BE SORTED AND SUMMARIZED BY FIRST"/1X,
     +    "        SECOND,THIRD AND FOURTH DIGIT OF THE ACTIVITY NUMBER"//)
      PRINT 887
  887 FORMAT(1X,"SORTED BY")
      READ 888,N1,N2,N3,N4
      ISK=1
      SK(1)=N1
      IF(N2.EQ.0) GO TO 899
      SK(2)=N2
      ISK=2
      IF(N3.EQ.0) GO TO 899
      SK(3)=N3
      ISK=3
      IF(N4.EQ.0) GO TO 899
      SK(4)=N4
```

```
1590        ISK=4
1600   888  FORMAT(4(I1,1X))
1610   899  PRINT 889
1620   889  FORMAT(1X,"ACTIVITY RANGE -- FROM")
1630        READ 890,(A(J),J=1,4)
1640   890  FORMAT(4A1)
1650        PRINT 891
1660   891  FORMAT(1X,"TO")
1670        READ 892,(B(J),J=1,4)
1680   892  FORMAT(4A1)
1690        NRR=0
1700        DO 580 K=1,NRX
1710C ....CHECK FOR THE RANGE
1720        DO 583 JA=1,4
1730        ITABLE(99,JA)=KRETA(K,JA)
1740   583  CONTINUE
1750        CALL RANGE(A,B,ITABLE,NTEST,99)
1760        IF(NTEST.EQ.1) GO TO 580
1770        DO 581 KK=1,8
1780        IRETA(K,KK)=KRETA(K,KK)
1790   581  CONTINUE
1800        NRR=NRR+1
1810   580  CONTINUE
1820        DO 900 K=1,98
1830        IF(ITABLE(K,1).EQ.IBL) GO TO 900
1840        K1=K
1850        CALL RANGE(A,B,ITABLE,NTEST,K1)
1860        IF(NTEST.EQ.1) GO TO900
1870        CALL DISTA(NDIS,ITABLE(K,5),ITABLE(K,6),ITABLE(K,7),ITABLE(K,8),
1880+       ITABLE(K,9),ITABLE(K,10),NIND)
1890        TAREA=0.
1900        IF((ITABLE(K,11).EQ.1).OR.(ITABLE(K,11).GT.6)) GO TO 905
```

```
1910        IF(ITABLE(K,11).EQ.2) GO TO 904
1920C ....CURVE DISTRIBUTION
1930        NCUR=ITABLE(K,11)-2
1940        NSUM=0
1950        DO 980 MM=1,NIND
1960        NSUM=NDIS(MM,3)+NSUM
1970  980 CONTINUE
1980        NPART=0
1990        DO 908 L=1,NIND
2000        WW=0.
2004        INDIS=NDIS(L,3)
2010        DO 909 M=1,INDIS
2020        NPART=NPART+1
2030        X=(10.*NPART)/NSUM
2040        W=0.
2050        DO 910 KK=1,10
2060        K1=KK-1
2070        W=W+POLCO(NCUR,KK)*(X**K1)
2080  910   CONTINUE
2090        WW=WW+W
2100  909   CONTINUE
2110        ADIS(L)=WW
2120        TAREA=TAREA+ADIS(L)
2130  908   CONTINUE
2140        GO TO 915
2150C ....STRAIGHT LINE
2160  904   DO 917 L=1,NIND
2170        ADIS(L)=NDIS(L,3)
2180        TAREA=TAREA+NDIS(L,3)
2190  917   CONTINUE
2200  915   DO 919 L=1,NIND
2210        NRR=NRR+1
```

```
2220        IRETA(NRR,7)=(ADIS(L)/TAREA)*ITABLE(K,12)
2230        IRETA(NRR,8)=(ADIS(L)/TAREA)*ITABLE(K,13)
2240        DO 920 LL=1,4
2250        IRETA(NRR,LL)=ITABLE(K,LL)
2260  920   CONTINUE
2270        IRETA(NRR,5)=NDIS(L,1)
2280        IRETA(NRR,6)=NDIS(L,2)
2290  919   CONTINUE
2300  900   CONTINUE
2310C ....
2320C .....SORT IRETA TABLE ACCORDING TO SORT REQUEST
2330C .....SORTED BY ACTIVITY NUMBER,YEAR MONTH
2340C .....N1,N2,N3,N4, SORT KEYS
2350  952   NTEST=0
2354        INRR=NRR-1
2360        DO 922 K=1,INRR
2370        IF(IRETA(K,N1).LT.IRETA(K+1,N1)) GO TO 922
2380        IF(IRETA(K,N1).GT.IRETA(K+1,N1)) GO TO 950
2390        IF(N2.EQ.0) GO TO 940
2400        IF(IRETA(K,N2).LT.IRETA(K+1,N2)) GOTO 922
2410        IF(IRETA(K,N2).GT.IRETA(K+1,N2)) GO TO 950
2420        IF(N3.EQ.0) GO TO 940
2430        IF(IRETA(K,N3).LT.IRETA(K+1,N3)) GO TO 922
2440        IF(IRETA(K,N3).GT.IRETA(K+1,N3)) GO TO 950
2450        IF(N4.EQ.0) GO TO 940
2460        IF(IRETA(K,N4).LT.IRETA(K+1,N4)) GO TO 922
2470        IF(IRETA(K,N4).GT.IRETA(K+1,N4)) GO TO 950
2480C  ....DATE SORT
2490  940   IF(IRETA(K,6).LT.IRETA(K+1,6)) GO TO 922
2500        IF(IRETA(K,6).GT.IRETA(K+1,6)) GO TO 950
2510        IF(IRETA(K,5).LT.IRETA(K+1,5)) GO TO 922
2520        IF(IRETA(K,5).GT.IRETA(K+1,5)) GO TO 950
```

```
2530        GO TO 922
2540  950   DO 951 KK=1,8
2550        ISTO(KK)=IRETA(K,KK)
2560        IRETA(K,KK)=IRETA(K+1,KK)
2570        IRETA(K+1,KK)=ISTO(KK)
2580  951   CONTINUE
2590        NTEST=1
2600  922   CONTINUE
2610        IF(NTEST.EQ.1) GO TO 952
2620C .....
2630C ....REPORT PRINT
2640        NPAGE=0
2650        DO 704 K=1,18
2660        VAST(K)=AST
2670  704   CONTINUE
2680        DO 701 K=1,ISK
2690        A(K)=IRETA(1,SK(K))
2700  701   CONTINUE
2710        NX=K
2720        NL=61
2730        CALL HEADING(NPAGE,PR1,PR2,TITLE,OM,OD,OY,SK,VAST,ISK,IRETA,
2740+       NX,NYC,NL)
2750        NSOM=IRETA(1,5)
2760        NSOY=IRETA(1,6)
2770        TCOST=IRETA(1,8)
2780        TMNH=IRETA(1,7)
2790        CCOST=0.
2800        CMNH=0.
2810        DO 705 K=2,NRR
2820        DO 710 N=1,ISK
2830        NQ=SK(N)
2840        IF(A(N).NE.IRETA(K,NQ))GO TO 750
```

```
2850   710  CONTINUE
2860C ....SAME ACTIVITY NUMBER
2870   711  IF(IRETA(K,6).NE.NSDY) GO TO 756
2880        IF(IRETA(K,5).NE.NSDM) GO TO 756
2890        TCOST=TCOST+IRETA(K,8)
2900        TMNH=TMNH+IRETA(K,7)
2910        GO TO 705
2920C .....NEW MONTH
2930C .....
2940   756  CCOST=CCOST+TCOST
2950        CMNH=CMNH+TMNH
2960        NX=K
2970        IF(NLINE.GE.61)CALL HEADING(NPAGE,PR1,PR2,TITLE,DM,DD,DY,SK,
2980+       VAST,ISK,IRETA,NX,NYC,NL)
2990        CALL WRLIN(NSDY,NSDM,TMNH,CMNH,TCOST,CCOST,VAST,NYC,NLINE)
3000        TCOST=0.
3010        TMNH=0.
3020        NSDM=NSDM+1
3030        IF(NSDM.EQ.12) NYC=1
3040        IF(NSDM.LE.12) GO TO 711
3050        NSDM=1
3060        NSDY=NSDY+1
3070        GO TO 711
3080C .....NEW ACTIVITY
3090   750  CCOST=CCOST+TCOST
3100        CMNH=CMNH+TMNH
3110        CALL WRLIN(NSDY,NSDM,TMNH,CMNH,TCOST,CCOST,VAST,NYC,NLINE)
3120        DO 752 N=1,ISK
3130        A(N)=IRETA(K,SK(N))
3140   752  CONTINUE
3150        NX=K
3160        CALL HEADING(NPAGE,PR1,PR2,TITLE,DM,DD,DY,SK,VAST,ISK,IRETA,NX,
```

```
3170+       NYC,NL)
3180        NSDM=IRETA(K,5)
3190        NSDY=IRETA(K,6)
3200        TCOST=IRETA(K,8)
3210        TMNH=IRETA(K,7)
3220        CCOST=0.
3230        CMNH=0.
3240  705   CONTINUE
3250C ....END OF REPORT
3260        CCOST=CCOST+TCOST
3270        CMNH=CMNH+TMNH
3280        CALL WRLIN(NSDY,NSDM,TMNH,CMNH,TCOST,CCOST,VAST,NYC,NLINE)
3290        NYC=-2
3300        CALL HEADING(NPAGE,PR1,PR2,TITLE,DM,DD,DY,SK,VAST,ISK,IRETA,
3310+       NX,NYC,NL)
3320        WRITE(6,760)
3330  760   FORMAT(1X,"WOULD YOU LIKE TO RUN ANOTHER REPORT  YES,NO")
3340  761   READ 870,AA
3350        IF(AA.EQ.ANO) STOP
3360        IF(AA.EQ.AYES) GO TO 460
3370        GO TO 761
3380  460   WRITE(6,461)
3390  461   FORMAT(1X,"WOULD YOU LIKE TO ENTER ANOTHER FILE? YES,NO")
3400  462   READ 870,AA
3410        IF(AA.EQ.ANO) GO TO 835
3420        IF(AA.EQ.AYES) GO TO 432
3430        GO TO 462
3440  905   WRITE(6,926)(ITABLE(K,J),J=1,4),ITABLE(K,11)
3450  926   FORMAT(1X,"INVALID TYPE OF CURVE FOR ACTIVITY",2X,4A1,5X,I2)
3460        GO TO 900
3470        END
3480        SUBROUTINE REFIL(ITABLE,NRR,IRETA)
```

```
3490       DIMENSION ITABLE(99,13),IT(13),IRETA(1000,8),IDIRE(10),IFN(4)
3610 840   READ (1,863) NCX,(IT(J),J=1,13)
3620  863  FORMAT(I2,1X,4A1,1X,7(I2,1X),I7,1X,I6)
3630       IF(NCX.EQ.0) GO TO 900
3640       IF(NCX.GT.99) GO TO 825
3650       IF(IT(11).EQ.1) GO TO 882
3660       DO 810 K=1,13
3670       ITABLE(NCX,K)=IT(K)
3680  810  CONTINUE
3690       NRR=NCX
3700      GO TO 840
3710  825  PRINT 860
3720  860  FORMAT(1X,"NUMBER OF ACTIVITIES MUST BE LESS THAN 99, IF YOUR",
3730+      " INPUT IS COMPLETE ENTER 0 AS A LINE NUMBER"/)
3740       GO TO 840
3750 882   READ(1,879) (IDIRE(J),J=1,10)
3760  879  FORMAT(I2,1X,4A1,1X,3(I2,1X),I7,I8)
3770       IF(IDIRE(1).EQ.99) GO TO 840
3780       NRR=NRR+1
3790       DO 881 K=1,6
3800       L=K+1
3810       IRETA(NRR,K)=IDIRE(L)
3820  881  CONTINUE
3830       IF(IDIRE(8).EQ.0) GO TO 880
3840       IRETA(NRR,7)=IT(12)*(IDIRE(8)/100)
3850        IRETA(NRR,8)=(IDIRE(8)/100)*IT(13)
3860       GO TO 882
3870  880  IRETA(NRR,7)=IDIRE(9)
3880       IRETA(NRR,8)=IDIRE(10)
3890       GO TO 882
3910 900   RETURN
3920       END
```

```
3930        SUBROUTINE DISTA(NDIS,NSM,NSD,NSY,NEM,NED,NEY,NIND)
3940        DIMENSION NDIS(180,3)
3950C  .....FIRST MONTH
3960        NIND=1
3970        NDIS(1,1)=NSM
3980        NDIS(1,2)=NSY
3990        IF((NSY.EQ.NEY).AND.(NSM.EQ.NEM)) GO TO 40
4000        NDIS(1,3)=(30-NSD+1)
4010        IF(NSY.EQ.NEY) GO TO 50
4020C  .....FIRST YEAR
4030        IF(NSM.EQ.12) GO TO 200
4040        KK=NSM+1
4050        DO 10 K=KK,12
4060        NIND=NIND+1
4070        NDIS(NIND,1)=K
4080        NDIS(NIND,2)=NSY
4090        NDIS(NIND,3)=30
4100   10   CONTINUE
4110C  ....YEARS BETWEEN
4120  200   IF(NEY-NSY.EQ.1) GO TO 60
4130        KA=NSY+1
4140        KB=NEY-1
4150        DO 15 K=KA,KB
4160        DO 14 L=1,12
4170        NIND=NIND+1
4180        IF(NIND.GT.180) GO TO 100
4190        NDIS(NIND,1)=L
4200        NDIS(NIND,2)=K
4210        NDIS(NIND,3)=30
4220   14   CONTINUE
4230   15   CONTINUE
4240        GO TO60
```

```
4250C ......ONE MONTH SPAN
4260  40    NDIS(1,3)=NED-NSD+1
4270        RETURN
4280C ......ONE YEAR SPAN
4290C ......MONTH BETWEEN
4300  50     IF(NEM-NSM.EQ.1) GO TO 55
4310        KA=NSM+1
4320        KB=NEM-1
4330        DO 52 K=KA,KB
4340        NIND=NIND+1
4350        NDIS(NIND,1)=K
4360        NDIS(NIND,2)=NSY
4370        NDIS(NIND,3)=30
4380  52    CONTINUE
4390C  .....LAST MONTH
4400  55    NIND=NIND+1
4410        NDIS(NIND,1)=NEM
4420        NDIS(NIND,2)=NSY
4430        NDIS(NIND,3)=NED
4440        RETURN
4450C  ....LAST YEAR
4460C  ........MONTHS BETWEEN
4470  60    KK=NEM-1
4480        IF(NEM.LE.1) GO TO 62
4490        DO 65 K=1,KK
4500        NIND=NIND+1
4510        IF(NIND.GT.180) GO TO 100
4520        NDIS(NIND,1)=K
4530        NDIS(NIND,2)=NEY
4540        NDIS(NIND,3)=30
4550  65    CONTINUE
4560C ......LAST MONTH
```

```
4570   62    NINC=NIND+1
4580         IF(NIND.GT.180) GO TO 100
4590         NDIS(NIND,1)=NEM
4600         NDIS(NIND,2)=NEY
4610         NDIS(NIND,3)=NED
4620         RETURN
4630   100   WRITE(6,600)
4640   600   FORMAT(1X,"ONLY 15 YEARS ALLOWED FOR ACTIVITY DURATION,ACTIVITY",
4650+        " WAS TRUNKATED")
4660         RETURN
4670         END
4680         SUBROUTINE RANGE(A,B,ITABLE,NTEST,M)
4690         INTEGER A(4),B(4),ITABLE(99,13)
4700C    ....NTEST=0 COST CODE IS ACCEPTED
4710C .......NTEST=1 COST CODE IS REJECTED
4720         NTEST=0
4730         DO 10 K=1,4
4740         IF(A(K).LT.ITABLE(M,K)) GO TO 20
4750         IF(A(K).EQ.ITABLE(M,K)) GO TO 10
4760         NTEST=1
4770         RETURN
4780   10    CONTINUE
4790   20    DO 15 K=1,4
4800         IF(ITABLE(M,K).LT.B(K)) RETURN
4810         IF(ITABLE(M,K).EQ.B(K)) GO TO 15
4820         NTEST=1
4830         RETURN
4840   15    CONTINUE
4850         RETURN
4860         END
4870         SUBROUTINE HEADING(NPAGE,PR1,PR2,TITLE,NM,ND,NY,SCOCO,VAST,
4880+        IS,IA,K,NYC,NL)
```

```
4890        DIMENSION VAST(18),TITLE(12)
4900        DIMENSION IA(1000,8)
4910        INTEGER SCCCO(4)
4920        INTEGER SC(4)
4924        INTEGER PR1,PR2
4930        DATA IBL/" "/,LF/" "/
4940        N=65-NL
4950        WRITE (6,200) (LF,J=1,N)
4960  200   FORMAT(1X,66A1)
4970        WRITE(6,201)
4980  201   FORMAT(" ----")
4990        DO 100 N=1,4
5000        SC(N)=IBL
5010  100   CONTINUE
5020        WRITE(6,200) (LF,J=1,4)
5030        IF (NYC.NE.-2) GO TO 1
5040        NYC=0
5050        RETURN
5060  1     CONTINUE
5070        NL=15
5080        NPAGE=NPAGE+1
5090        DO 102 N=1,IS
5100  -     NQ=SCOCO(N)
5110        SC(NQ)=IA(K,NQ)
5120  102   CONTINUE
5130        NYC=1
5140        WRITE(6,10)NPAGE
5150   10   FORMAT(1X,T3,"DANIEL INTERNATICNAL CORPORATION",T58,
5160+       "PAGE NO.",1X,I4)
5170        WRITE(6,20)(TITLE(J),J=1,10),PR1,PR2,NM,ND,NY
5180  20   FORMAT(1X,T3,10A4," PROJ. ",A4,A2,T58,"DATE ",I2,"-",I2,"-",I2)
5190        WRITE(6,30)(VAST(J),J=1,17)
```

```
5200    30  FORMAT(1X,T3,17A4)
5210        WRITE(6,40)
5220    40  FORMAT(1X,T13,"PROJECT CONTRCL FORECAST SYSTEM")
5230        WRITE(6,45)(SC(J),J=1,4)
5240    45  FORMAT(1X,T3,"MANHOURS AND COST FOR:",1X,4A1)
5250        WRITE(6,30)(VAST(J),J=1,17)
5260        WRITE(6,50)
5270  50    FORMAT(1X,T5,"YEAR",T11,"MONTH",T23,"MANHOURS",T34,"CUMMULATIVE",
5280+       T49,"COST",T58,"CUMMULATIVE")
5290        WRITE(6,51)
5300  51    FORMAT(1X,T35,"MANHOURS",T49,"IN $",T59,"COST IN $")
5310        WRITE(6,30)(VAST(J),J=1,17)
5320        RETURN
5330        END
5340        SUBROUTINE WRLIN(NSDY,NSDM,TMNH,CMNH,TCOST,CCOST,VAST,NYC,NLINE)
5350        DIMENSION VAST(18),AMON(12,3)
5360        DATA AMON/"JANU","FEBR","MARC","APRI","MAY","JUNE","JULY","AUGU",
5370+       "SEPT","OCTO","NOVE","DECE","ARY","UARY","H","L"," "," "," ",
5380+       "ST","EMBE","BER","MBER","MBER"," "," "," "," "," "," "," ",
5390+       " ","R"," "," "," "/
5400C .....IF NYC=1 PRINT LINE
5410        IF(TMNH.LT.0) TMNH=0.
5420        IF(CMNH.LT.0)CMNH=0.
5430        IF(TCOST.LT.0)TCOST=0.
5440        IF(CCOST.LT.0)CCOST=0.
5450         NINE=19
5460        IF(NYC.EQ.1) GO TO 80
5470        IF(NSDM.NE.1) GO TO 30
5480    80  WRITE(6,60)NINE,NSDY,(AMON(NSDM,J),J=1,3),TMNH,CMNH,TCOST,CCOST
5490        NLINE=NLINE+1
5500  60    FORMAT(1X,T5,2I2,2X,2A4,A1,2X,F10.0,2X,F11.0,2X,F10.,2X,F11.0)
5510        IF(NSDM.EQ.12) GO TO 20
```

```
5520        NYC=0
5530        RETURN
5540   20   WRITE(6,61)(VAST(J),J=1,17)
5550        NLINE=NLINE+1
5560    61  FORMAT(1X,T3,17A4)
5570        NYC=0
5580        RETURN
5590    30  WRITE(6,62)(AMON(NSDM,J),J=1,3),TMNH,CMNH,TCOST,CCOST
5600        NLINE=NLINE+1
5610    62  FORMAT(1X,T11,2A4,A1,2X,F10.0,2X,F11.0,2X,F10.0,2X,F11.0)
5620        NYC=0
5630        RETURN
5640        END
```

Appendix C

References

1. D. W. Halpin, "A Data-Based Methodology for Specifying Construction Project Duration," Technical Report P-14, Construction Engineering Research Laboratory (CERL), Champaign, Illinois, 1973.